CHAPTER 1

Forensic Quality Management and Era of Standardization: Where the Rubber Meets the Road in Challenging Environments

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1.1 Introduction

The journey of quality management in forensic science stretches from its medieval roots in European guild systems to its current status as a prominent global normative framework (Ross and Neuteboom, 2020a). This chapter aims to examine how standardization and quality assurance (QA) have shaped forensic science, particularly when confronted with operational realities marked by complexity, resource limitations, and institutional instability. Recognizing that it is ludicrous to envisage forensic science without QA, this chapter broadens the debate by asking: Can the logical framework and application tools developed in industrial settings genuinely serve the purposes of and complex demands from forensic science, or do they risk constraining the field's scientific autonomy and interpretive flexibility? The relevance of this question is accentuated in complex and high-risk operational contexts. A foundational framework for its resolution is derived from the Sydney Declaration (SD) (Roux et al., 2022), which is further elaborated in this chapter.

1.1.1 Historical Development and the Rise of Standardization

Throughout history, the idea of quality has changed significantly. Quality was first associated with artisanal excellence in medieval guilds, where standards

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were determined by each artisan's level of skill (Juran, 1995). However, as industrial capitalism grew, quality became institutionalized. Inspection systems were created during the Industrial Revolution (1760–1840) to keep an eye out for product flaws because mass production required consistency. Quality as a managerial and technical concept originated from this (Juran, 1995; Garvin, 1988).

The Industrial Revolution ushered in a factory-based logic centered on efficiency, scale, and quality control via end-point inspection. In the early 20th century, Frederick W. Taylor (1911) developed scientific management, or Taylorism, which was key to future developments. To increase productivity and efficiency, Taylor promoted the standardization of work tasks, the study of motion and time, and stringent control over work procedures. Taylorism prioritized conformity over creativity and succeeded in rationalizing industrial production, but it also treated workers like mere cogs in a machine. Under Taylorism, the terms "quality" and "uniformity," and "control" came to mean attributes that could be quantified, managed, and enhanced. Organizations' approaches to quality in the ensuing decades would be significantly impacted by this mechanistic viewpoint. This approach measured quality after production rather than addressing root causes of error. The subsequent advent of statistical quality control in the 1920s represented a shift toward prevention, advocating that quality should be embedded within each step of the process.

The influential "quality gurus" of the 20th century, such as Walter Shewhart, W. Edwards Deming, Joseph Juran, and Kaoru Ishikawa, established principles like cause-and-effect analysis, control charts, quality circles, and continuous improvement cycles (e.g., the PDCA cycle: plan-do-check-act or Deming Cycle). Deming (1986) questioned the Taylorist rigidity (Juran, 1995). This signaled the shift from quality control to quality culture, a paradigm where quality is a result of institutional commitment, values, and behaviors as well as processes (Juran, 1995; Garvin, 1988). A quality culture is more than just following rules; it is a shared philosophy where everyone in the company takes ownership of enhancing performance. It places more emphasis on learning than blame, teamwork over hierarchy, and reflexivity over routine (Garvin, 1988). People's thoughts, decisions, and relationships with the goal of their work are all influenced by quality. It also acknowledges the importance of judgment, context, and ethical discernment, as not all values can be expressed in metrics.

While developed for manufacturing, these concepts gradually found their way into fields like forensic science (Ross and Neuteboom, 2020a,b; Hazard et al., 2014). In this field, this cultural view of quality is especially pertinent (Hazard, 2014; Margot, 2011). Industry standards like ISO/IEC 17025 had a significant impact on forensic laboratories' adoption of quality management systems in the late 20th century (Ross and Neuteboom, 2020a). These systems, which reflected the Taylorist legacy of control and uniformity, placed a strong emphasis on personnel qualifications, equipment calibration, traceability, and procedural documentation. However, drawbacks emerged when these models were applied within forensic contexts.

According to Hazard et al. (2014: 1772), "The forensic science community struggles today with the comprehensive quality approach because it failed to develop its own approach, instead mistakenly copying the work from the manufacturing sector." This claim draws attention to a structural shortcoming in forensic science: the lack of a high-quality model derived from its unique features. Forensic science is concerned with the detection, recognition, examination, and interpretation of traces – vestiges of past events that are often imperfect, incomplete, and not reproducibly or statistically generated, as they arise from uncontrolled and usually unpredictable circumstances (Weyermann and Roux, 2021). Further, forensic procedures require expert interpretation, disciplinary diversity, and adaptation to particular judicial contexts. For these reasons, the adoption of normative models, while offering some control mechanisms, is insufficient to guarantee their dependability and applicability (Olson and Ramsay, 2025). While forensic practice necessitates methodological flexibility and a rigorous scientific approach that transcends procedural formalism (Mousseau et al., 2025), the industrial model is predicated on repetition and the standardization of production processes that are ill-fitted to the nature of forensic science.

The novel ISO 21043 standard seeks to provide forensic science with an international framework tailored to its specific needs (Berger, 2025; Morrison et al., 2025). ISO 21043 aims to capture the complexities of forensic processes, from evidence collection to interpretation and reporting. While ISO/IEC 17025 has long been a more general reference point, but one that would work in tandem with the new ISO standard. Berger (2025) identifies Part 4, focusing on interpretation, as a fundamental contribution. It includes a structured decision tree and standardized vocabulary that aim for greater clarity and consistency. However, the pursuit of uniformity can also unintentionally generate rigidity, hampering the necessary adaptability in jurisdictions characterized by diverse and contradictory legal traditions, resources, and institutional practices, as is particularly the case in the Global South. On the other hand, from a forensic data science perspective, Morrison et al. (2025) offer a more critical review. They value the focus on empirical validation and the likelihood-ratio framework as ways to ensure clarity and robustness of processes. However, they point out conceptual flaws, such as unclear definitions of key terms, and assert that ISO 21043 is not intended as an accreditation standard. This limits its immediate practical impact, making it more of a goal than a rule.

The views of Berger (2025) and Morrison et al. (2025) clarify the dual essence of ISO 21043: it would serve, on the one hand, as a tool for possible harmonization and, on the other hand, as a reminder of the persistent problems of global inequality. If we fail to recognize the differences in resources and experience between the Global North and the Global South, the idea of true international uniformity could remain a utopian ideal rather than becoming operationally functional. In any case, the epistemological essence, semiotic scope, and rigor remain a deficiency that must be resolved.

In the context of forensic science, these industrial practices were adopted to foster institutional trust, deliver consistent outcomes, and enable external audits. Over time, a logic of "structural control," including protocols, accreditations, validations, and document traceability, began to replace reliance on individual expert competence. This transition, presented as necessary for public trust and traceability (Wilson-Wilde, 2018; Ballantyne and Wilson-Wilde, 2020), redefined forensic work as a series of validated, auditable, and measurable steps, akin to a production chain spanning from crime scene to court report.

However, there has been ongoing discussion in the field about this "era of standardization." On the one hand, supporters contend that industrial manufacturing-based quality systems are necessary to uphold the validity and consistency of practice. Others caution that rigorous adherence to these frameworks may jeopardize scientific autonomy and diminish the importance of expert judgment, particularly in complex or unique cases that are challenging to adapt to standard operating procedures (Hazard, 2014; Crispino et al., 2022; Mousseau et al., 2025). This raises a crucial query: To what extent do these systems fit the purposes of forensic science?

1.1.2 Refocusing on Quality: From Checklist Culture to Scientific Judgment

In forensic science, discussions about quality are often limited to management tools, accreditation, and protocols. Despite their necessity, these mechanisms risk losing their meaning if separated from the conceptual foundations that support them. True quality must be based on solid foundations of logical reflection, semiotics, and epistemology (Roux et al., 2022; Crispino, 2024; Illes et al., 2020; Cole, 2013; Margot, 2011).

From an epistemological perspective, forensic science must clarify the types of knowledge it generates, as well as its limits and scope. It is important to critically examine the concepts of certainty, probability, and plausibility rather than taking them for granted. In the absence of this, quality control could guarantee uniformity of the process, ignoring the true reliability of the findings. Forensic science reveals deficiencies in reasoning and case-specific research, primarily attributable to training that emphasizes specialization and repetitive methodologies (Cole, 2013; Illes et al., 2020). To tackle this issue, active learning strategies are suggested, incorporating problems, projects, and real-world experiences that enhance critical thinking and teamwork (Illes et al., 2020). At the same time, its practice takes place in a unique epistemic culture that is shaped by data that cannot be repeated, institutional rules, and the pressure of courts, all of which affect how forensic knowledge is produced and validated (Cole, 2013). The semiotic aspect is equally significant (Crispino, 2024; Crispino et al., 2022; Roux et al., 2022). According to Crispino (2024), forensic science must be reimagined from its foundations, as a trace is not merely a tangible object; it is a sign that requires recognition and interpretation to uncover its meaning. Although Bayesian statistics and regulatory reforms help, they are unable to completely eradicate bias or the intricacy of judicial reasoning (Dror, 2025). Bayesian statistics offers a useful prescriptive framework for logically organizing evidence, but its applicability is constrained by the interpretative intricacies of judicial processes. Peirce's semiotics[1] enhances this quantitative methodology by incorporating the examination of meanings and contexts into the evaluation of the probative value of forensic evidence (Crispino, 2024: Roux et al., 2022). This semiotic proposal emphasizes that all inferences are interpretive, with various meanings being assigned by laypeople, judges, and scientists. Therefore, without incorporating the human element, technical quality alone is inadequate. The strength of forensic science lies in its ability to articulate findings within their context, following a coherent and logical argumentative framework that clearly demonstrates their value (Crispino, 2024; Roux et al., 2022). Forensic traces, consisting of specific signs such as fingerprints, genetic profiles, bone fractures, and injuries in general, for example, "do not speak for themselves," but rather must be deciphered. Interpretive frameworks influenced by context and conventions give them probative value. Evaluating the reliability of forensic interpretations requires understanding this semiotic mediation (Crispino, 2024). Finally, logic serves as the basis for the reasoning that connects hypotheses to evidence. Clear and compelling argumentative structures are just as important to quality as technical precision (Roux et al., 2022).

The notion of quality in forensic science has always attracted scrutiny. As early as the 1980s, during a presentation to a meeting of the International Association of Forensic Sciences (IAFS) in Oxford, UK in 1984, Margaret Pereira (1985) questioned whether implementing quality management was affordable. Her own response continues to resonate to this day: "The real question is whether we can afford not to" (Neuteboom et al., 2023). This early viewpoint signaled a significant turning point by highlighting that quality is a necessity for credible and valid forensic findings, not a luxury. Ross and Neuteboom (2020a) frame the evolution of forensic quality management as a deliberate, adaptive process rather than a passive adoption of outside standards. They describe it as an "odyssey" requiring robust organizational commitment, a culture of continuous improvement, and sufficient resources, operational and financial.

The increasing focus on compliance in professional and scientific fields could unintentionally turn quality into just a matter of following the rules. Formal systems and standardized procedures are essential for maintaining

[1] The value of Peirce semiotics lies in the necessary and sufficient triadic decomposition of signs, in which the perception of the sign (representation or ground) results in another signification (the object) via a necessary Interpretant, which can be a function, a resultant, a thought, or a judgment (Crispino, 2024).

accountability and consistency; however, they may unintentionally restrict professional activities to bureaucratic efficiency at the expense of substantive excellence. In these situations, critical thinking, creativity, and epistemological reflection are pushed to the side, which makes it hard for professionals to question their assumptions, deal with complex uncertainties, or adapt to new problems. Relying too much on checklists can also give you a false sense of security, hiding deeper weaknesses that only expertise, experience, and scientific reasoning can reveal. Forensic science requires more than just following the rules. It requires the ability to understand scientific principles, the ability to look at traces that may or may not become evidence later in a bigger picture, and the courage to admit when one does not know something. So, it is important to build a strong scientific culture. This involves not only enhancing technical skills but also fostering critical reflection, promoting continuous learning, and implementing rigorous assessments to evaluate the depth of knowledge. QA should find a middle ground between keeping procedural safeguards in place and giving experts the freedom to use their professional judgment in ways that make their fields more reliable and trustworthy.

1.1.3 Balancing Standardization and Professional Autonomy

According to Willis (2010), the true quality of forensic science is determined by the practitioner's judgment, training, cognitive ability, and adaptability. Excessive focus on compliance and documentation can stifle discourse about the evidential significance, boundaries of expertise, and the abductive reasoning central to forensic interpretation. This is especially problematic in challenging environments, such as conflict zones or humanitarian crises, where adaptability, contextual awareness, and epistemic sensitivity are indispensable. In such settings, quality must be a reflexive, logical practice, not simply a certificate of compliance.

Neuteboom and Ross (2024) notably distinguish between "adopters" (often institutional managers, seeking comfort in standards and procedures) and "skeptics" (typically forensic scientists, valuing flexibility and critical thought). They argue this divide need not be irreconcilable; quality systems should cultivate environments for open scientific discourse, not close them off. This tension, between rigid, document-driven approaches and dynamic, adaptive practice, lies at the heart of contemporary forensic science.

1.1.4 The Epistemic Gap and the Need for Scientific Culture

Forensic science is defined as "a case-based research-oriented, science-based endeavor to study traces" (Roux et al., 2022: 2). The value of a trace is determined not only by procedural conformity but also by its epistemic meaning within a logical explanatory narrative (Hazard, 2014). Interpreting traces requires cognitive abilities, critical thinking, reasoning, logic, and hypothesis formation (Kelty et al., 2011, 2017, 2023, 2024), rarely addressed in current quality systems (Neuteboom et al., 2023). Even though ISO/IEC 17025 stipulates competence requirements (clause 6.2), assessments often focus on practical and technical skills, leaving cognitive and interpretive competencies under-evaluated. This gap exposes a preference for documentary compliance over well-informed scientific judgment (Neuteboom et al., 2023). In this situation, certain changes have been made to meet the needs of forensic laboratories. ANAB[2] AR 3125:2023 is one example[3]. It adds forensic-oriented requirements to ISO/IEC 17025, covering topics like ethics, safety, environmental conditions, and staff education. ILAC G-19:06/2022[4] also encourages a modular approach to the forensic process, from gathering evidence to interpreting it. It shows how to use ISO/IEC 17025 and ISO/IEC 17020 in forensic situations. The ISO 21043 series also covers the whole forensic science process (Morrison et al., 2025; Berger, 2025), from terminology (Part 1) to recognition, recording, transport, and storage (Part 2), analysis (Part 3), interpretation (Part 4), and reporting (Part 5) (Morrison et al., 2025). This makes each step of forensic practice stronger (Berger, 2025). The critique by Neuteboom et al. (2023) remains entirely valid, notwithstanding recent adaptations. Forensic practice remains at risk of prioritizing checklists and administrative procedures over the development and application of cognitive and interpretive expertise. This reinforces the need for accreditation systems to encourage more critical thinking.

Standardization, moreover, has sometimes prioritized process over purpose, sidelining the forensic discipline’s core aims: reconstructing, preventing, and understanding criminal phenomena (and others harmful to society) (Roux et al., 2021). This dissociation between means and ends has resulted in an instrumental and fragmented vision that privileges formal compliance over substantive understanding. As Margot (2011) argues, what is needed is not just a culture of quality, but a culture of forensic science itself, built on research, critical training, and philosophical reflection.

1.1.5 From Administrative Compliance to Critical Forensic Science

The true value of quality in forensic science does not reside in codified norms, but in integrating those norms with scientific reasoning and context-specific practice. Willis (2010) warns that accreditation can create a false sense of infallibility; technical compliance does not guarantee correct results (Olson and Ramsay, 2025). The most recent and telling illustration of this point is the problems experienced by the Queensland DNA laboratory in Australia.

[2] See https://webstore.ansi.org/?source=blog&_gl=1*1dztitn*_gcl_au*MTExNDM0NjE2MS4xNzU2ODE3MTE4

[3] See https://blog.ansi.org/anab/what-is-ar-3125/?utm_source=chatgpt.com

[4] See https://ilac.org/latest_ilac_news/revised-ilac-g19-document-published/?utm_source=chatgpt.com

Despite significant work undertaken by management to address the problems, many reports (Sofronoff, 2022; Bennett, 2023; Walvisch et al., 2024; Budowle, 2025; Wright et al., 2025) confirmed that accreditation does not suffice to guarantee quality (Olson and Ramsay, 2025).

Technical reform alone will not work unless there is a significant change in culture as well. Therefore, while professionalization has emphasized certification and accreditation, the field must now seek a deeper transformation: the cultivation of a robust and reflective scientific culture. Forensic practice inherently relies on expert interpretation (Hazard, 2014; Crispino et al., 2022). Quality goes beyond just avoiding mistakes; it includes inference, context, and coherence, and it requires both epistemological and administrative evaluation. It also includes relevance, purpose, continuous improvement, and long-term impact that goes beyond just following the rules. This means recognizing the diversity of forensic work, from state-of-the-art laboratories to resource-limited field sites, and promoting principles that guide practice beyond mere procedure. It is important to emphasize that basic scientific foundations like those described in Roux et al. (2022) do not go against QA; instead, they work together. Fundamental principles establish the conceptual and ethical framework for sound scientific practice, guaranteeing that research is valid, transparent, and pertinent. QA is a way to set those principles into action and strengthen them through standards, controls, and procedures.

1.1.6 Chapter Roadmap

These theoretical and practical tensions, between standardization and scientific judgment, compliance and critical reflection, and process and purpose, are present in all forensic contexts. However, they become significantly magnified in operational settings marked by structural violence[5], institutional and financial instability, or fragmented regulatory landscapes. In such challenging environments, the risks of over-reliance on procedural norms, the under-development of expertise, or the neglect of context-specific judgment can have profound consequences not only for scientific credibility but for justice and humanitarian outcomes. It is precisely here that the scientific foundation assumes special importance.

Recognizing these challenges, the remainder of this chapter critically examines the potential and limits of forensic quality management, focusing particularly on how these systems function (or fail) under the pressure of real-life, high-stakes contexts. A key argument is that broader foundational frameworks, such as the SD, can play a fundamentally complementary role in maintaining quality when conventional mechanisms are insufficient. Importantly, the SD is not

[5] Structural violence is a form of violence that is not seen but is caused by social, economic, and political inequalities that are built into institutions. It restricts opportunities, rights, and access to essential resources, causing suffering and exclusion without direct aggression. It shows up as poverty, racism, discrimination, and inequality in the system (Galtung, 1969; Farmer, 2004).

intended to replace traditional quality frameworks, but rather to provide a comprehensive strategic foundation for forensic science that remains valid in all environments, both standard and nonstandard. By rooting practice in its core principles, it enables reliability, effectiveness, and scientific integrity where conventional quality control frameworks may fail. It thus ensures that forensic science remains agile, transparent, and relevant in a rapidly changing world.

By exploring how forensic scientists address the intersection of ever-evolving standards, resource constraints, and complex cases, the chapter seeks to illuminate both the paths forward and the pitfalls to avoid. In doing so, it advocates for a model of forensic science that is not only procedurally rigorous but also resilient, reflective, and sensitive to the diverse real complexities in which it is practiced, especially based on rigorous scientific foundations.

1.2 Quality Management in Forensic Science: From Tradition to Transformation

1.2.1 Purposes and Institutional Justification

The primary justification for forensic quality management has historically been the need to strengthen public and judicial confidence in forensic science. Lentini's (2009) "*Forensic Quality Triangle*" is a common way to show that forensic science is of high quality. It includes three important parts: certification, accreditation, and standardization. These components function interdependently to enhance the reliability of forensic evidence and to maintain public and judicial confidence in its application.

Certification is all about how good someone is at doing something. It requires more than mere education or experience; practitioners must empirically validate their proficiency in the accurate and consistent application of established methodologies. Ballantyne and Wilson-Wilde (2020) contend that competence can solely be demonstrated through blind proficiency testing conducted in conditions that replicate actual casework. Certification, then, makes professionals responsible, enhances clarity, and gives the courts confidence that expert testimony is based on proven skill.

Accreditation, on the other hand, is about how well an institution can do its job. It means that independent groups officially recognize that laboratories follow international standards like ISO/IEC 17025 or the new ISO/IEC 21043 and have strong quality management systems. According to Wilson-Wilde (2018), accreditation proves that laboratories not only have the technical skills they need but also have processes that are consistent, can be audited, and are focused on continuous improvement. This dimension is directly related to institutional QA systems, which use documentation, peer review, and internal audits to lower the chances of mistakes, contamination, or bias in the forensic process.

Standardization is the base that gives us the common set of methods and procedures. International efforts, like those led by ISO/TC272, set standards that everyone agrees on that set the minimum standards for collecting, analyzing, interpreting, and reporting evidence. Lentini (2009) emphasized that without recognized standards, both certification and accreditation lose effectiveness, as there would be no clear criteria for defining and evaluating good practice. These three pillars, along with strong institutional QA systems, make sure that forensic science gives results that are valid, reliable, and can be compared across countries. They also protect the validity of forensic evidence in court decisions and boost public trust in forensic institutions.

In legal contexts, where expert evidence can decisively influence decisions that affect fundamental rights, ensuring the reliability and transparency of forensic findings is an ethical, scientific, and legal imperative. From this perspective, quality systems aim to minimize errors, document decision-making, reduce operator variability, and establish formal mechanisms for continuous improvement (Neuteboom et al., 2023). However, beyond its technical-operational function, forensic quality has acquired symbolic and strategic value within institutions. In many countries, especially those with weakened, transitional, or reforming judicial systems, the implementation of quality systems has been interpreted as a sign of modernization, professionalization, and transparency. Within this framework, accreditation operates not only as a tool for external validation but also as an instrument of institutional governance, allowing laboratories to align with international standards, position themselves within globalized networks, and access funding and international cooperation.

In this sense, quality in forensic science should not be understood solely as a set of standardized procedures, but as an institutional practice aimed at ensuring the epistemic integrity of forensic knowledge, its legal utility, and its social relevance. That is, the ultimate purpose of forensic quality management is not only to optimize processes but mainly to build legitimacy and public trust before the public, the judicial system, and the scientific community.

The implementation of quality systems thus constitutes a form of epistemic governance that harmonizes multiple dimensions: technical, legal, organizational, and ethical.

It is a scaffolding that contributes to stabilize forensic practices, mitigate the risk of errors or biases, and promote a more rigorous dialogue between science and law. At the same time, as various critical voices have pointed out (Roux et al., 2022; Crispino and Roux, 2017; Crispino et al., 2022; Ross and Neuteboom 2020a,b; Neuteboom and Ross, 2024; Willis, 2010, among other), it also represents a regulatory mechanism that, when applied rigidly or without context, can constrain scientific autonomy and critical thinking.

For this reason, understanding the purposes and institutional justification of forensic quality requires a critical perspective that is historically informed and epistemologically aware. To progress toward quality models that not only adhere to standards but also genuinely elevate the epistemic, ethical, social, and humanitarian values, as well as their diversity in the contexts where forensic science is applied, it is essential to recognize its multifaceted nature and various contexts. Understanding and solidifying basic principles is just as important, since these are the ideas and methods that make forensic practices trustworthy and valid. Without a clear understanding of these principles, any model of quality could end up being just about following the rules instead of encouraging ongoing improvement and strengthening the role of forensic science in society as a whole.

1.2.2 Toward a Forensic Scientific Culture

Addressing the current tensions in forensic quality management requires more than revising technical standards; it calls for the cultivation of a true forensic scientific culture (Kirk, 1963; Margot, 2011; Hazard, 2014). This entails educating and training professionals who are not only proficient in following protocols but who can integrate quality principles with critical thinking, interpretive reasoning, and epistemic sensitivity (Kelty et al., 2011, 2017, 2023, 2024). Quality should not be reduced to the mechanical application of procedures; rather, it must be understood as a deliberative and reasoned practice, where forensic inference is not merely documented but thoroughly justified.

The interpretation of traces in forensic science requires professional judgment, use of appropriate inference (in particular abductive reasoning and analogy), and adaptation to specific contexts (Weyermann and Roux, 2021). These aspects, which are highly dependent on the practitioner and the environment, are difficult to codify into universal procedures and often fall outside the scope of quality systems. As a result, quality runs the risk of being equated with procedural conformity rather than the validity of inference. This view can lead to an "illusion of reliability" based more on documentary compliance than on the actual epistemic value of the forensic inference (Weyermann and Roux, 2021; Crispino et al., 2022; Roux et al., 2022).

The implementation of standards or the use of structural controls as stand-ins for scientific proficiency is insufficient to characterize a culture of quality in forensic science. A genuine forensic science culture is built upon practitioners with rigorous scientific training, grounded in strong university education, and deeply engaged with the unique challenges and questions specific to the field (Margot, 2011; Bruenisholz et al., 2024). Many laboratories were founded in institutional structures where hierarchy took precedence over the critical advancement of knowledge. This led to disjointed forensic practices, undertrained staff, and a tendency to function as mere producers of results, particularly in the field of DNA (Margot, 2011). Because every case is a real investigative challenge, a culture of forensic science excellence requires not only a strong scientific basis but also the analytical and reflective ability to detect, examine, and evaluate traces in complicated contexts. This procedure acknowledges forensic science as a distinctive field that includes the responsible communication of its findings, critical interpretation, and acceptance of uncertainty (Roux et al., 2022; Hazard, 2014; Ballantyne et al., 2024).

In forensic reasoning, Hazard (2014) asserts that relevance is not an inherent characteristic of a trace; instead, it arises from the relationship between the trace and the case context, facilitated by inferences and interpretive methodologies. In this context, a trace possesses no intrinsic value; its significance emerges only when the trace is acknowledged, chosen, and interpreted by the scientist, who employs their training, experience, intuition, and contextual understanding to ascribe meaning to it. Relevance is understood as a dynamic and relational construct that surpasses the material attributes of the trace, situating it within a particular explanatory and operational context.

Different ways of reasoning are used to build relevance. The trace is linked to reasonable hypotheses that try to explain why the trace is present in the situation being looked into by using abductive, inductive, or deductive reasoning. This cognitive process enables the conversion of the trace into a clue, which serves as a sign with explanatory significance within the narrative of events (Crispino, 2024; Weyermann and Roux, 2021; Crispino et al., 2022). So, relevance does not just depend on the trace itself; it also depends on how well the scientist can fit it into a useful and rational story about the investigation (Weyermann and Roux, 2021; Crispino et al., 2022).

Hazard (2014) also emphasizes that relevance is always relative, contextual, and temporal. There is no single rule that can objectively and definitively say which trace is important; its importance depends on the situation, the organization, and the person. In this context, two dimensions can be identified: factual relevance, which pertains to the acknowledged connection between the trace and the case, and appropriate relevance, which assesses whether the resources expended in gathering and analyzing the trace are warranted by the anticipated informational advantages. The significance of the trace is established through an interpretive and contextual process that embodies forensic culture alongside the scientist's expertise and experience. Bitzer et al. (2015) assert that the evaluation of traces in forensic settings has conventionally depended on what they term external indicators. These are standardized and generalizable criteria, like how often a certain trace occurs statistically, how reliable the analytical methods are, how well it matches records or databases, or how well it can be used in court. These indicators give an objective frame of reference, but they are mostly not connected to the specific situation of the investigation. The authors, on the other hand, talk about the idea of the utility of the clue, which moves the focus from these outside factors to the investigation's internal logic. From this standpoint, the utility of a trace is not solely contingent upon its rarity or technical precision, but rather on its efficacy in facilitating the resolution of the particular case, whether by diminishing uncertainty, reinforcing or undermining hypotheses, or recalibrating the investigative approach. Bitzer et al.'s (2015) proposal seeks to transcend the static perspective of external indicators by contextualizing the evaluation of the trace within the dynamic interplay between the informational potential of the clue and the cognitive requirements intrinsic to the investigative process. The authors also suggest the idea of “expected utility” as a way to figure out which traces are most important before doing the analysis. In this way, conscious and efficient selection is encouraged, redundancies are avoided, and the contribution of forensic science is maximized.

Crispino (2024) underscores that these deficiencies cannot be rectified solely through protocols, accreditations, or technical enhancements, as the fundamental issue resides in the essence of the trace and in the assignment of meaning within decision-making frameworks. His proposal to advance forensic semiotics through the integration of Peirce’s framework opens a novel and largely unexplored trajectory in the field. In this context, the concept of the interpretant elucidates the human contribution to the construction of meaning in forensic findings, highlighting its biases, limitations, and possibilities. In the current era of artificial intelligence in forensic science (see Chapter 2), it is essential to distinguish the contributions of these technologies, effective in data management and pattern recognition, from the reflective reasoning of the human brain. Crispino (2024) underscores that interpretive judgment, grounded in semiotic logic, will remain indispensable: only the human intellect can ascribe meaning to signs within their judicial and social contexts. We should not forget this aspect today when trying to build trust in a system that is increasingly using automation and artificial intelligence.

This approach emphasizes the value of instructional strategies that develop interpretive skills, moving beyond purely technical instruction to promote reflective practice and genuine scientific literacy. Ultimately, building a forensic scientific culture means fostering a professional ethos centered on inference, transparency, and epistemic responsibility. In such a culture, quality is not an external imposition but the natural outcome of scientifically engaged and critically aware practitioners.

1.3 The Standardization Era: The Forensic Shift and Industrial Ideals

One of the most significant, and contentious, changes in the field’s recent development is the consolidation of standardization as the predominant paradigm in forensic science. This movement, which was initially motivated by the justifiable need to increase public and judicial confidence in forensic results, progressively embraced the concepts, metaphors, and working logic of industrial production. Key manufacturing concepts like consistency, efficiency, control, and repeatability were incorporated into the institutional jargon of forensic quality management. Accreditation became a strategic and symbolic objective as laboratories were reorganized around technical documentation, procedural compliance, and performance metrics.

These modifications had unexpected epistemological repercussions even though they brought about much-needed accountability and error-reduction mechanisms. Originally intended to be a field based on contextual reasoning based on the examination of isolated incidents, forensic science started to lose sight of its original purpose. Procedural completeness was frequently given precedence over the deeper significance of scientific reasoning due to the emphasis on process control and conformance. Because of this, there is less room for professional judgment that includes using inference with contextual sensitivity.

Furthermore, the industrial paradigm frequently prioritizes quantifiable results over qualitative findings. This reinforces a concept of quality that runs the risk of becoming synonymous with bureaucratic correctness rather than scientific robustness by creating a tension between what can be measured and what cannot. This change affects how forensic work is perceived, practiced, and valued in addition to how it is managed, as many commentators have pointed out (Neuteboom and Ross, 2024; Willis, 2010). According to Neuteboom and Ross (2024), this adoption has been so intense that in many institutional settings a "compliance culture" has taken root, one that replaces scientific deliberation with documentary adherence. In their analysis of the divide between "adopters" (managers, auditors, technicians) and "skeptics" (forensic scientists, researchers), the authors describe a system in which compliance trumps critical thinking, and where the effectiveness of procedures is assessed more by their auditability than by their epistemic relevance. A narrow and technocratic view of forensic practice is implied when forensic science quality is reduced to rigorous adherence to accreditation systems and standardized procedures. The forensic professional, who is in charge of producing and interpreting knowledge, is reduced to a supporting role in this framework, while the emphasis is placed on external auditors and evaluators, who ultimately end up having undue control over the process (Willis, 2010).

Form over substance, documentary conformance over scientific reasoning and the expert's critical autonomy are all weakened by this logic. As a result, forensic procedures may be formally sound but may be shallow in their interpretation and insensitive to context. As the foundation of forensic quality, competency, which is defined as both technical knowledge and the ability to reason, communicate, and make sense of complex situations, needs to be strengthened immediately. This is done through rigorous scientific training and a professional judgment ethic.

1.3.1 Mean vs. Purpose

A type of operational fragmentation has been facilitated by the extensive use of standardization in forensic science, whereby the trace examination and interpretation are separated into distinct technical tasks. The expert's integrated responsibility over the overall narrative is weakened by this compartmentalization, which also tends to impede holistic reasoning. The growing gap between means and purpose is highlighted by Roux et al. (2021), who note that standardization tends to prioritize the how over the why, which frequently weakens the contextual meaning of findings.

Therefore, forensic work runs the risk of becoming less of a scientifically significant investigation and more of a procedural compliance exercise. Instead of evaluating professionals' critical interpretation, epistemic reflexivity, or judicial reasoning skills, this "bureaucratization" of forensic knowledge has fostered a culture where professionals are primarily judged on their ability to complete forms, adhere to established workflows, and pass audits. According to Neuteboom et al. (2023), technical conformance is given disproportionate weight in current quality management frameworks, which rarely evaluate cognitive or interpretive competence. According to their global survey, formal competence standards did not consistently identify, evaluate, or track critical thinking, logical reasoning, hypothesis formulation, and judgment, all of which are critical cognitive skills. Rather, quality systems continue to be primarily concerned with procedural results.

This change has significant ramifications. The development of propositions at the heart of forensic science cannot be replaced by standard operating procedures (SOPs), even though they may guarantee consistency in quantifiable steps. According to Roux et al. (2021), forensic science may lose its investigative and inferential character if quality is confused with compliance, which would undermine its capacity to make a significant societal contribution beyond the presentation of evidence in Court. Further, Neuteboom et al. (2023) underscore a critical concern in forensic science: the pronounced disparity between the focus on technical competencies and the insufficient emphasis on cognitive competencies. The former are typically well-defined and consistently evaluated through standardized protocols, whereas the latter are inadequately defined and infrequently subjected to formal evaluation mechanisms. This imbalance is an issue because forensic practice involves more than just using tools; it also includes critical thinking, logical reasoning, making informed decisions, and coming up with hypotheses in situations where there is a lot of uncertainty. The absence of systematic recognition and evaluation of these skills poses the risk of cultivating professionals who possess technical proficiency yet remain inadequately equipped to navigate the interpretative complexities intrinsic to the field. Consequently, Neuteboom et al. (2023) emphasize the necessity for quality management frameworks that explicitly incorporate cognitive competencies as a fundamental aspect of forensic practice.

In the end, an overemphasis on procedural fidelity runs the risk of transforming forensic science into a system of "quality on paper," where real scientific robustness is replaced by the appearance of rigor. Quality frameworks must reintegrate cognitive competence, interpretive reasoning, and the ability to deal with uncertainty in order to restore purpose. These are qualities that cannot be pre-programmed and must be developed through education, mentoring, and a change in institutional culture.

1.3.2 The Forensic Quality Paradox

Modern forensic science faces a structural paradox brought about by the era of standardization: the more standardized practice grows, the more likely it is to stifle its critical, interpretive, and inferential elements. In addition to being theoretical, this paradox shows up in the day-to-day work of forensic specialists, who must balance the need to follow established protocols with the need to draw conclusions that are supported by science in situations that are frequently complicated and uncertain. According to Willis (2010), the shift from science to process has left less room for scientific contemplation, creating a perilous false sense of technical certainty that does not always equate to improved outcomes.

The forensic professional is often reduced to an executor of protocols rather than an active interpreter of evidence, which creates a sort of epistemic alienation (Willis, 2022). Current quality systems, as Crispino et al. (2022) caution, have a tendency to assess the proper application of the procedure rather than the applicability of the reasoning, which can validate results that are technically correct but scientifically dubious. Compliance, not comprehension, is being measured. The fundamental cause of the forensic quality paradox is this discrepancy between operational validation and epistemological validity. Moreover, the paradox is made more apparent in situations where the ideal laboratory that the standards model differs greatly from the actual working conditions, as happens in Latin America (e.g., see Chapters 7–10). Additionally, the stress of keeping records, following rules, and conquering these obstacles is frequently a tiresome conundrum in real life. According to Willis (2010), quality that is only concerned with processes can fall short in situations where experience, ethical awareness, and contextual judgment are more important than strict adherence to a process. It is true that forensic quality cannot be boiled down to a technical assurance. It must be viewed as an ethical and epistemological practice that involves taking accountability for the interpretation of the evidence, the reasoning behind conclusions, and the communication of uncertainties. Hazard (2014) notes that the ability of forensic reasoning to produce sound, explicit, and verifiable inferences, rather than the process followed, is what gives it legitimacy. Although helpful, the quality system should critically support scientific discussion rather than take its place.

Therefore, the paradox is not that quality is a barrier in and of itself, but rather that its careless and decontextualized application may actually erode the very thing it was meant to enhance: public confidence in forensic science (Zhang and Lu, 2025). Gaining this trust requires more than just accreditation and certification credentials; it also requires methodological openness, sound judgment, and the capacity to adjust to actual difficulties. Rebalancing the axis between means and ends is the answer. Standards are means, not ends in and of themselves. If we lose this distinction, we may start to value things that are easier to measure more highly than those that are important (Roux et al., 2021).

1.4 Quality in Challenging Environments: Where the Rubber Meets the Road

In complex, demanding, and challenging forensic situations, such as those that occur during armed conflicts, mass violence, large-scale disasters, or serious human rights violations, the quality systems that are often recommended internationally present significant strategic, operational, and ethical problems. Operationally, insecurity, lack of resources, and time constraints make it difficult to strictly adhere to standardized protocols, which could even slow down urgent responses. Strategically, the presence of numerous actors and interests requires a level of flexibility and adaptability that inflexible frameworks often fail to consistently provide. The mechanical application of procedures can conflict with ethical principles such as valuing victims and being sensitive to different cultures. Also, worrying about strictly following standardized systems and protocols can make people forget about the epistemological core of forensic work for a number of reasons. First, strict adherence to procedures may prioritize compliance over critical reflection, turning complex reasoning into routine mechanical tasks. Second, protocols are often made to make sure that things are done consistently and that people are held accountable, but they have difficulty to capture the nuances that give meaning to traces in an investigation. Third, when practitioners concentrate excessively on evading procedural errors, they may overlook the interpretative and inferential aspects that genuinely produce knowledge. As a result, forensic science may be diminished to mere technical proficiency instead of its epistemic. For these reasons, we need a more flexible and context-sensitive quality management system. It must balance technical rigor with ethical imperatives and remain true to the primary goal of forensic science.

The rigid application of standards designed for controlled laboratory environments can prove unsuitable or even counterproductive in these settings. As evidenced in forensic investigations conducted in the Democratic Republic of the Congo, quality management must adapt to environments marked by chronic uncertainty, insecurity, and deep technical and logistical constraints, without compromising the integrity of the evidence or the safety and dignity of victims (Komar et al., 2021). Currently, using and maintaining one of these standardized international mechanisms in this scenario is very difficult, if not impossible. The 2002 Bali bombing and the MH17 crash investigation serve as prime examples of how forensic science must adapt when conventional ISO-compliant and validation-based procedures are no longer fully applicable

(AFP 2022, 2024,). Since the crash of MH17 took place in an area of active conflict, approved protocols like chain-of-custody controls, verified collection techniques, and ISO 17025 laboratory conditions could not be implemented right away (Ranson, 2015). Under strict limitations, forensic teams were forced to rely on triage principles, scientific integrity, and adaptable interagency coordination. Similar to the Bali bombing, which featured a scene of widespread casualties and fragmented infrastructure, the scope and urgency of victim identification exceeded the stringent deadlines and documentation required by traditional quality systems.

Such conditions highlight the need to rethink the concept of quality through a more flexible, contextual, and purpose-driven lens. Rather than imposing externally developed standards that often are disconnected from challenging environments, it becomes imperative to construct situated quality models that prioritize methodological coherence, transparency in reasoning, and epistemic awareness. These frameworks should aim not only guarantee the technical credibility of forensic results but also to ethically engage with the lived realities of affected populations and the professionals working under extreme conditions. This includes acknowledging that many forensic processes in these environments require creative adaptation, expert judgment, and moral discernment that cannot be fully captured by prescriptive procedures.

Such an approach does not imply abandoning the core principles of quality, such as reliability, traceability, or continuous improvement, but rather reconfiguring them to advance forensic science as a human endeavor, centered on traces, responsive to context, and grounded in inference. Quality, in this sense, must transcend mere procedural compliance to become an enabler of meaningful investigation, scientific integrity, and posthumous dignity. It should be understood as a dynamic and adaptive framework that reinforces the legitimacy of forensic work not only in the eyes of judicial systems, but also among victims' families, local communities, and the community at large.

Ultimately, reimagining quality in this way opens the door to a more resilient and ethically grounded forensic practice, one capable of operating effectively in the face of structural inequalities, institutional fragility, and profound humanitarian challenges. In these complex scenarios, quality should be a means of supporting justice, and human rights, not an obstacle to them.

Accredited forensic laboratories and their quality management systems often appear robust, but this often ignores or distorts the reality of forensic work, generating a popular myth among judicial authorities: if you are not accredited, your results lack scientific quality. In Africa and Latin America, where there is a high demand for forensic services, many efforts have been made and important experiences have been gained that go against the idea that only accredited laboratories can produce scientifically valid results. These areas, which are often limited by a lack of resources and red tape, have shown that it is possible to create strict standards and make a real difference in justice systems even when they are not formally accredited. This shows that scientific quality doesn't just depend on an accreditation seal; it also depends on how dedicated professionals are, how innovative they are, and how well they can meet society's urgent needs (see Chapters 7–). Unfortunately, certification and accreditation are not necessarily or always present, but that does not mean their quality is diminished. The chaotic, unstable, and resource-limited conditions found in real-life settings, particularly those affected by armed conflict, institutional fragility, or systemic violence, rarely resemble the controlled and regulated environment of the laboratory, or expected in standards.

Forensic professionals in many areas are forced to operate with little equipment, under duress from authorities, communities, or security threats, and with limited access to logistical support and training. Without modification, following procedures that are simple to execute in an ISO-accredited laboratory become nearly impossible. For instance, in situations where refrigeration is unavailable, electricity is unstable, or legal protections are inadequate, it can be extremely challenging to maintain chain of custody, ensure sample integrity, or complete standardized documentation.

Furthermore, the applicability, viability, and even morality of forensic interventions may be compromised by strict adherence to international standards without contextual calibration. In these situations, forensic quality needs to be redefined as adaptive competence – the ability to uphold scientific integrity while adapting to changing and resource-constrained circumstances, rather than procedural perfection. In addition to technical proficiency, this calls for cultural awareness, fortitude, and moral discernment. A constructive way forward would be to recognize these constraints openly and to promote flexible, context-sensitive mechanisms that can complement or substitute for full ISO-style procedures when resources are scarce. Rather than dismissing the work of laboratories or professionals who cannot meet every formal requirement, justice systems could encourage the adoption of minimum quality standards, simplified documentation models, and locally adapted practices that still protect the integrity of evidence. International organizations and regional networks might also play a role by providing technical guidance, training, and peer support aimed at strengthening reliability without imposing unattainable benchmarks. Such approaches would allow forensic professionals to operate responsibly in adverse environments while preserving the credibility of their work, demonstrating that scientific rigor is possible even outside ideal laboratory conditions.

For these situations, the SD (Roux et al., 2022) could provide a broader strategic perspective that would allow forensic practitioners to uphold scientific integrity while adapting to operational constraints. Indeed, the SD recommends strategic application of forensic principles, such as openness, critical thinking, and flexibility, guaranteeing that scientific integrity can be maintained even in the absence of completely controlled settings (Olckers and Ben Khelil, 2024).

1.4.1 Brief Overview of the Sydney Declaration

Forensic science has been under the microscope for decades and in more recent time deemed "in crisis" (Roux et al., 2015, 2021; Koheler et al., 2023). If the NRC (2009) and PCAST (2016) reports are probably still fresh in mind, Paul L. Kirk was already pointing out in 1963 that in forensic science "progress has been technical rather than fundamental, practical rather than theoretical, transient rather than permanent" (Kirk, 1963: 235). As highlighted by Roux et al. (2015, 2021, 2022), the crisis may be attributed to an absence of a unified vision and a commonly held understanding of forensic science, coupled with the imperative to reorient the discipline from methodological means toward its foundational purpose. Therefore, in 2022, after decades of questioning, and in a context of growing technological fragmentation within the scientific discourse on forensic science, an informal collective of eminent forensic scientists (academics and practitioners) leveraged the organization of 2023 International Academy of Forensic Science (IAFS) conference in Sydney, Australia, to initiate a critical and holistic reflection on forensic science directions and core principles as a discipline in its own right (Roux et al., 2022; Crispino et al., 2022). The Sydney Declaration was born[6].

The SD constitutes a significant rethinking of forensic science as a practice based on basic epistemic principles (Roux et al., 2022; Olckers and Ben Khelil, 2024; Ribaux et al., 2024; Buzzini, 2024). The SD, which puts the trace at the epistemological center and places it above technology or legal disciplines, has been praised as a daring attempt to rethink forensic science from the ground up. It has had a good initial impact, as evidenced by its promotion in a variety of fora across the globe, its translation into many different languages, and its utility being demonstrated in event reconstruction (Miranda et al., 2023), forensic science development, and operations, for example. The large number of citations in peer-reviewed literature further showed how helpful the SD is to place various forensic practices within a common framework, particularly in interdisciplinary and reflexive contexts (Ribaux et al., 2024). However, this promising initial support should be contrasted against some commonly reported challenges like the perceived ambiguity around the SD's purpose, the use of complex academic language, and uncertainty about its relationship to existing QA frameworks. This conversation within the forensic science community and its stakeholders is ongoing and necessary to bridge the gap between theory and practice. Ultimately, the SD's legitimacy will be determined by its capacity to unite a forensic community that is able to withstand the system's centrifugal forces and validate forensic science as a separate, important, and socially relevant discipline (Ribaux et al., 2024).

[6] An audiovisual resource specially prepared can also be freely viewed at the following link: https://www.youtube.com/watch?v=AaZwQkEpyKE&t=5s

The SD aims to establish a "shared understanding and acceptance of the essence of forensic science, its purpose, and fundamental principles. It provides a definition of forensic science and seven fundamental principles that emphasize the pivotal role of the trace as a vestige, or remnant of an investigated activity." The principles address critical features of forensic science, "such as context, time asymmetry, the continuum of uncertainties, broad scientific knowledge, ethics, critical thinking, and logical reasoning" (Roux et al. 2022: 1).

The SD defines forensic sciences as: "a case-based (or multi-case-based) research-oriented, science-based endeavor to study traces, the remnants of past activities (such as an individual's presence and actions), through their detection, recognition, recovery, examination, and interpretation to understand anomalous events of public interest (e.g., crimes, security incidents)" (Roux et al., 2022: 2). It also comprises of seven principles, articulating "the nature and ground of this discipline:

1. Activity and presence produce traces that are fundamental vectors of information.
2. Scene investigation is a scientific and diagnostic endeavor requiring scientific expertise.
3. Forensic science is case-based and reliant on scientific knowledge, investigative methodology and logical reasoning.
4. Forensic science is an assessment of findings in context due to time asymmetry.
5. Forensic science deals with a continuum of uncertainties.
6. Forensic science has multidimensional purposes and contributions.
7. Forensic science findings acquire meaning in context." (Roux et al., 2022: 2)

The SD offers a foundational reconceptualization of forensic science, shifting the focus from procedural compliance and technical outputs to the essence of what forensic science is and does. Through its definition, the Declaration recenters the discipline around its core epistemology: understanding past events through traces. This definition moves beyond the constraints of laboratory-bound or accreditation-driven models. It acknowledges that forensic science is inherently investigative, interdisciplinary, and dynamic, an approach that resonates particularly well in complex, uncertain, and resource-limited contexts. It recognizes that forensic work is not just about producing laboratory reports but about generating meaningful, contextually situated knowledge that can inform decisions in justice, security, and humanitarian domains. The seven fundamental principles further solidify this framework by grounding forensic science in its scientific and contextual nature The SD embodies the semiotic essence of forensic science (Crispino, 2024).

One common criticism of the SD is that it does not seem to accurately reflect the quality standards and procedures used in accredited forensic laboratories.

This comes from the fact that the SD does not explicitly refer to methods or quality management practices. But this omission should not be seen as opposition. The Declaration does not compete with or replace accreditation frameworks; instead, it sets out general rules that work well with them. It is important to make this difference clear so that there are no misunderstandings and to show that the Declaration and accreditation have different but important roles in forensic science. This impression stems from the fact that the SD does not directly address standardized methods or quality management systems such as those found in ISO frameworks. However, this lack of action should not be interpreted as opposition. Rather, it demonstrates the purpose of the Declaration: to establish universal and transversal principles to guide forensic practice in all operating systems. In this context, quality is not limited to compliance with control standards; it also includes ensuring that results are truly fit for purpose. ISO systems provide the technical basis for control and assurance, but the SD offers the big picture that unites these changes but in a different dimension, a foundational dimension. The SD was meant to stay neutral about organizational structures and accreditation systems from the start. It is not meant to replace them, but to complement them by ensuring that all technical standards are grounded in enduring, fundamental principles.

1.4.2 The Sydney Declaration as an Overarching Strategic Quality Framework for Challenging Environments

As shown above, traditional QA frameworks like ISO/IEC 17025 in forensic science are meant to protect scientific integrity, technical competence, and consistency in settings with a lot of resources. These frameworks make sure that everything can be traced and that people are held accountable by setting strict rules for how things should be done and how they should be documented. But forensic work can't stop just because these kinds of systems are not available or are not practical. In this way, the SD offers a flexible, scientifically sound, and principle-based framework that not only works with current QA systems but can also be used as a guiding framework when formal accreditation is not possible. Even when traditional standards exist, the SD provides the foundational epistemological framework upon which these systems are built. The SD does not compete with ISO-based approaches; instead, it strengthens their legitimacy and fills important gaps in high-pressure, resource-limited, or ethically sensitive environments. This allows forensic science to move forward with integrity and flexibility. The Declaration helps forensic practitioners maintain scientific integrity while adapting to the realities of high-pressure, time-sensitive, or resource-limited settings (Olckers and Ben Khelil, 2024).

For example, within the African context, the SD presents a valuable opportunity to serve as a guiding framework that acknowledges the continent's unique structural complexities, institutional limitations, and sociopolitical diversity.

Its implementation goes beyond a mere statement of principles, offering practical guidance and relevance to the diverse forensic landscapes found across Africa (Olckers and Ben Khelil, 2024; Nkonyane, 2025).

This approach emphasizes the value of expert reasoning and contextual analysis as pillars of sound practice, rather than focusing on tools or infrastructure. Rather than prescribing rigid processes or techniques, the SD offers a set of foundational principles that guide forensic practice when standard operating procedures or validated methods are inaccessible, inapplicable, or underdeveloped. Rooted in the core scientific and philosophical foundations of forensic science, it enables practitioners to produce meaningful and defensible results in dynamic and uncertain contexts. The Declaration provides a strategic anchor for practice by emphasizing the "why" and "how" of forensic science, tracing human activity through scientific inquiry, while allowing flexibility at the operational and tactical levels to adjust methods, tools, and reporting strategies based on the context.

Key contributions of the SD in challenging environments include, but are not limited to:

1. Bridging the gap between rigid QA expectations and on-the-ground realities
2. Enabling transparent practice when conventional validation or accreditation pathways are unavailable
3. Maintaining scientific integrity without reliance on infrastructure-heavy models
4. Supporting adaptability in high-pressure, politically complex, or resource-constrained settings
5. Legitimizing innovation and responsive thinking in the face of novel challenges

In such environments, the Declaration enhances key aspects of forensic science, including reliability, effectiveness, relevance, flexibility, adaptability, and innovation, supporting the long-term resilience, and credibility of the discipline.

1.4.2.1 Enhancing Reliability Through Scientific Grounding

One of the core contributions of the SD lies in its ability to maintain scientific reliability even when traditional indicators of quality – such as accreditation, full validation, or formal SOPs – cannot be met. The Declaration emphasizes:

The trace as the central vector of information (Principle 1), focusing practitioners on the evidential link between presence, activity, and material remnants.

The use of a diagnostic during scene investigation (Principle 2), reinforcing the need for scientific rigor from the outset, including documentation, observation, and hypothesis testing.

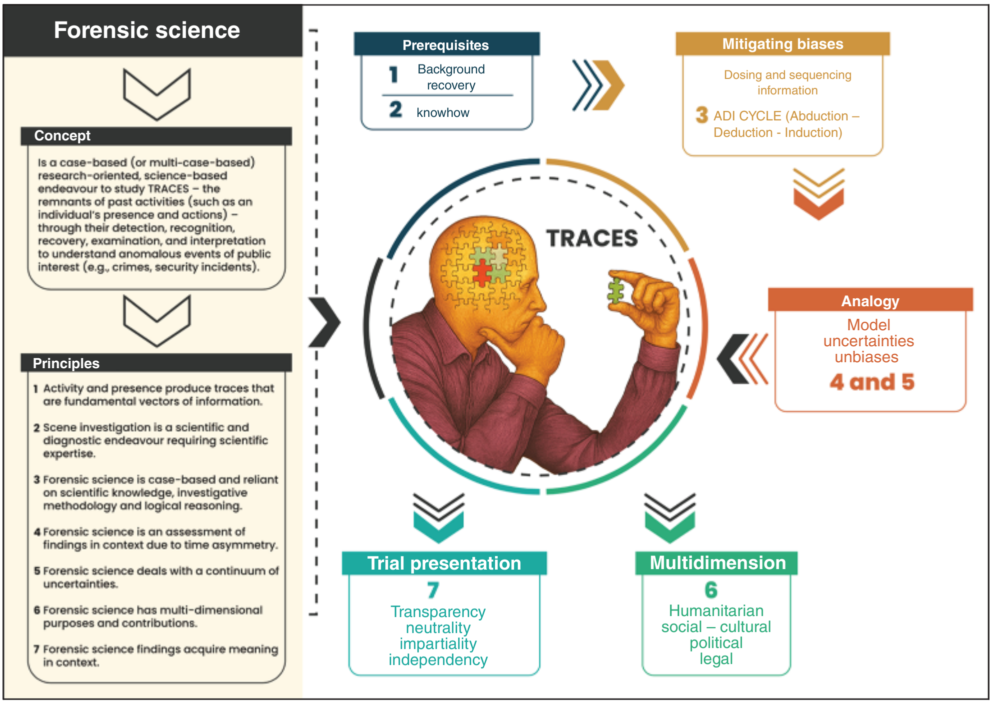

Figure 1.1 A conceptual summary and the theoretical framework that supports the epistemological and operationalizable orientation of the SD (Roux et al., 2022).

The need for contextual interpretation (Principles 4 and 7), ensuring that findings are not assessed in isolation but within the case narrative and investigative goals (Figure 1.1).

By grounding forensic science in the trace and the logic of interpretation, rather than solely in procedural conformity, the Declaration allows for transparent, reproducible reasoning even when technical repeatability is compromised. It encourages evidence-based justification of methods and decisions, reinforcing the trustworthiness of findings under challenging conditions.

1.4.2.2 Ensuring Relevance

In complex or resource-constrained environments, the relevance of forensic science should not be measured solely by its alignment with court-admissibility standards or formal QA frameworks. These settings, such as humanitarian operations, post-conflict investigations, or disaster response, often demand forensic contributions that extend beyond traditional legal proceedings. In such contexts, relevance is defined by the ability to provide timely, meaningful, and contextually appropriate information that supports broader goals, including intelligence, justice, fact-finding, human rights protection, public safety, or reconciliation.

The SD directly addresses this expanded notion of relevance. By recognizing the multidimensional contributions of forensic science (Principle 6), the Declaration broadens the scope of what is considered valuable work – moving beyond court-admissibility alone. It legitimizes forensic work that is strategically aligned with diverse objectives – even when traditional validation pathways or legal infrastructures are absent. This reframing enables practitioners to demonstrate value through impact rather than mere procedural compliance.

1.4.2.3 Supporting Effectiveness and Relevance in Diverse Contexts

The Declaration recognizes that forensic science is fundamentally case-based (Principle 3) and that its primary function is to support understanding of anomalous or criminal events through the study of traces. In doing so, it supports fit-for-purpose practices that respond to the specific demands, timelines, and contextual constraints of each case. This increases the likelihood that forensic outputs are meaningful and actionable within investigative, judicial, or humanitarian settings. In challenging environments, this means:

- Prioritizing relevance of results over rigid process conformity.
- Enabling triage-based approaches where full procedural adherence is not feasible but core scientific principles are still followed.
- Supporting multidisciplinary and cross-jurisdictional collaboration through a shared philosophical framework.

1.4.2.4 Enabling Flexibility and Adaptability

Modern forensic practice increasingly requires agility in the face of rapidly evolving operational conditions. And when standard QA models, designed for static environments, fail to accommodate the complexities of forensic engagements in challenging environments, the Declaration fosters a culture of adaptability and flexibility in the face of uncertainty into its foundational thinking (Principle 5) that is both scientifically grounded and ethically responsible through:

- Reflective practice in the presence of incomplete data
- Innovation in the use of methods and tools to study traces
- Iterative interpretation as more information becomes available

This makes the Declaration inherently responsive to change, whether technological, environmental, or geopolitical, allowing practitioners to adapt in real time, provided they remain grounded in the core principles of trace-based inquiry and contextual understanding.

1.4.2.5 Encourage Innovation While Maintaining Integrity

The SD recognizes that it is not always feasible to follow every QA step to the letter. In these situations, forensic professionals can still uphold forensic integrity by:

- Focusing on critical steps that preserve the chain of custody and the accuracy of results, even when some procedural elements might be simplified or altered.
- Ensuring transparent documentation of any deviations from standard practices, explaining the reasons behind these changes, and the efforts made to maintain scientific accuracy despite the limitations.
- Implementing "compensatory" quality control techniques that are suitable for the specific environment, such as creating additional safeguards or cross-checks, when full QA procedures cannot be followed.

Further, by encouraging foundational thinking, the Declaration creates space for methodological innovation, including new forms of data integration, interdisciplinary collaboration, and use of emerging technologies. Forensic science is not static; it evolves in response to new challenges and emerging technologies. The Declaration facilitates creative problem-solving in situations where established methods do not yet exist or cannot be applied as intended. In this way, the SD functions not only as a fallback when QA systems fail, but as a strategic compass for the future of forensic science, ensuring that the discipline remains scientifically robust, ethically grounded, and contextually responsive even as environments, technologies, and societal expectations continue to evolve. The SD positions forensic science as a discipline with multidimensional purposes and contributions (Principle 6). This view supports innovation not just in technologies or techniques, but in how forensic science aligns with justice, public interest, and human rights. By stepping beyond the constraints of narrow compliance models, the Declaration allows for:

- The development of context-sensitive methodologies,
- The inclusion of non-traditional actors and disciplines in forensic inquiry,
- The advancement of ethical, transparent, and socially responsible science.

Building on the foundational discussion of the African context, recent analyses by Olckers and Ben Khelil (2024) illustrate how the Declaration's principles are being translated into tangible action. For example, its adoption by key scientific bodies has initiated cross-sector dialogues, enhanced institutional recognition, and promoted ethical standards tailored to local realities. These developments not only strengthen the credibility of forensic work within Africa but also provide valuable models for adaptation in other regions facing similar challenges as well as enable African practitioners to align their work with universal scientific and ethical standards, while promoting institutional recognition and appreciation for their efforts (Smith and Horne, 2024).

Furthermore, their proposal highlights how the Declaration can act as a catalyst for transforming fragmented forensic ecosystems into coherent and functional frameworks. The SD has been formally adopted as a founding reference by the African Academy of Forensic Sciences (AFSA), which also encourages its translation and dissemination as a pedagogical and policy tool (Olckers and Ben Khelil, 2024). The authors note that its implementation not only guides practitioners in their daily work but also guides policymakers, academics, journalists, and judicial actors in understanding the boundaries and scope of forensic science. As a result, the Declaration not only redefines what forensic science is but also helps create a common language to defend its place in African legal systems (Olckers and Ben Khelil, 2024; Smith and Horne, 2024). In this sense, the Declaration is not only considered a scientific document but also a transformative platform that enables the imagination of a mature, autonomous, and socially and legally grounded African science.

Forensic services face various obstacles in many African countries, such as insufficient funding and training, and institutional deficiencies, including conceptualization. By ignoring local conditions and material constraints, regulatory models imported from more developed regions are often inapplicable. In recognition of such limitations, the International Forensic Strategic Alliance (IFSA) has developed minimum requirements guidelines to provide a foundational standard for forensic practice in resource-limited settings, offering a practical reference point where local protocols are absent or underdeveloped (IFSA, 2024). The absence of laboratories, training centers, and specialized agencies creates a structural dependence on international cooperation, whose solutions do not always address the specificities of the environment, and even if they do, they cannot be sustainable over time.

Alternatively, the Declaration emphasizes that forensic quality depends on the practitioner's ability to apply sound logical reasoning, maintain methodological transparency, and ensure argumentative traceability, and not solely on formal compliance with procedures or available technology. This allows reliable scientific conclusions to be drawn even in environments with inadequate infrastructure. Based on this reasoning, quality becomes a crucial principle guiding expert judgment in the face of ambiguity (Roux et al., 2022). This declaration's call to create a forensic science grounded in the reality of the challenging environment, with its own identity, based on universal values such as impartiality, traceability, and rigor, but adapted to local circumstances, is one of its most revolutionary and noteworthy features. The goal is to create morally sound and practical frameworks for action that address the problems and realities of the country, not to replicate the systems of other countries.

This approach defends scientific integrity and strengthens the ethical commitment to the truth in environments where forensic specialists are subject to institutional pressures or training limitations, even where they do not exist and are still developing. However, this perspective contrasts with the real situation in countries like the Democratic Republic of Congo, where there is virtually no organized forensic infrastructure, and capacity building for specialized human resources is still in its infancy. While international assistance has been crucial, thanks to the Office of the United Nations High Commissioner for Human Rights (OHCHR), through its UNJHRO office in the DRC and its forensic team, it focuses on contexts of violence and the fight against impunity. Its work combines specialized technical assistance, forensic operations, and strengthening access to justice. It also highlights how difficult it is to develop lasting capacities at the national level. A real challenge that is being faced.

In Latin America, the Middle East, and Asia, where forensic practice encounters equally complex and difficult circumstances, experiences akin to those Olckers and Ben Khelil (2024) detailed in the African context can also be seen (Bouzin et al., 2021, 2023; Howes et al., 2024). Forensic science is not always developed in well-equipped laboratories or under unified regulatory frameworks in these contexts, which are characterized by structural inequality, institutional limitations, chronic violence, or political instability. Conversely, forensic specialists must work in unstable, humanitarian, or disjointed justice systems, which emphasizes the applicability of the strategy put forth in the Declaration. As in the African region, the SD provides methodological and ethical guidance in these areas that goes beyond available resources and focuses on the fundamental goals of the discipline, including intellectual honesty in the face of uncertainty, scientific rigor, inferential clarity, and dedication to evidence. As a result, the reflections of Olckers and Ben Khelil (2024) and Roux et al. (2022) take on a universal dimension by reminding us that the principles of forensic science, not its instruments, constitute its true foundation. Consequently, the Declaration serves as a common platform for forensic scientists operating in complex environments globally and who share a steadfast dedication to justice, truth, and human dignity, despite its technical challenges.

1.4.3 Forensic Science in Practice: Intersecting the Mechanisms of Compliance with Epistemic Logic

The SD and conventional QA systems should not be perceived as contradictory or antagonistic criteria, as they operate in different dimensions. QA focuses on control, standardization, and verification. The SD, on the other hand, focuses on fundamentals, establishing the essential epistemological rules for forensic practice. It is also important to remember that the SD is the foundation upon which QA systems can be built or modified. When traditional models are unavailable or difficult to implement, the SD serves as a basis and guide for redesigning relevant frameworks in the operational environment. The SD seeks to rebalance these perspectives, reminding us that the true power of forensic science lies not in repeating steps, but in producing reliable, well-founded, and contextualized interpretations. According to this view, experience and technical tools are subordinated to the logical and persuasive skills of the expert, who assigns meaning to traces with transparency, while adapting to the unique context of each case.

The contemporary debate on quality management in forensic science highlights a tension between external manifestations of quality and its profound scientific content. Standardization through accreditation systems such as ISO 17025 was designed to generate confidence in processes, but has often led to a culture of regulatory compliance in which adherence to procedures is prioritized over the exercise of expert judgment (Neuteboom et al., 2023). This centralization of control can displace the interpretive authority of the scientist, replacing it with the apparent security offered by certificates and external audits (Ross and Neuteboom 2020a). As a result, the critical thinking and flexibility needed to address complex cases risk being overshadowed by the rigidity of protocols and general standards. As Neuteboom and Ross (2024) point out, this tension manifests itself in the gap between managers, who are adopters of standards, and professionals, who are skeptical and demand space for scientific thought, which poses the challenge of balancing transparency and flexibility so as not to sacrifice scientific essence for the sake of bureaucracy.

This phenomenon has been observed to reflect a general trend in the institutional management of forensic science, where respect for scientific thought is subordinated to compliance with procedures. This operational logic, supported by auditing and oversight procedures, reduces the importance of forensic work to the mere existence of official records, without necessarily assessing the quality of the logic that underpins them.

The adoption of mass production models in forensic science has led to this shift being interpreted as a component of an "industrial culture." However, forensic science is not a factory system. Judgment, interpretation, and situated knowledge are essential to its essence. Evidence presented in Court or to other stakeholders consist of deciphered data influenced by its context, the recovery environment, and the inferential chain that allows for the reconstruction of historical events.

Forensic quality management necessitates the equilibrium of normativity and scientific rationality, guaranteeing that formal compliance does not supplant critical reflection while promoting resilient, adaptable processes genuinely aimed at enhancing knowledge. The aim is to ensure that established procedures support, rather than limit, the interpretive abilities of forensic scientists. Practitioners should be equipped not only with operational skills but also with a solid foundation in logic, epistemology, and metacognitive strategies, especially when confronted with evidence that is ambiguous, incomplete, or open to multiple interpretations (Bruenisholz et al., 2024; Neuteboom et al., 2023).

Forensic practice relies heavily on the practitioner's ability to draw reliable inference from scarce and often incomplete or compromised data and resources in critical environments. This is especially the case in African or Latin American contexts, where fully equipped forensic laboratories and robust institutional protocols are generally lacking. In this case, forensic epistemology does not conflict with the absence of standards; rather, it is exemplified by the ability to act with responsibility, rigor, and judgment, even in uncertain situations (Roux et al., 2022).

Modern forensic science should not be viewed as a rigid dichotomy between a mechanistic model, which emphasizes auditability and compliance with formal regulations, and an introspective approach based on fundamentals, on essence. The SD argues that quality in forensic work transcends mere procedural standards and must be based on deeper principles: appropriate logical reasoning and interpretation of findings in context, and utmost commitment to ethics and transparency. Effective control and verification mechanisms are necessary to guarantee that information remains traceable and that processes are transparent and accessible to all. However, these alone do not guarantee the epistemic soundness of conclusions. The Declaration's call for introspection is not intended to supplant these tools; rather, it seeks to incorporate them into a comprehensive framework that views quality as a multidimensional construct encompassing technical rigor, interpretive soundness, and ethical responsibility. The real challenge for forensic science, therefore, is to integrate both levels so that formal procedures can contribute to a reflective, critical, and socially useful practice. In this second horizon, forensic science is emerging as a scientifically rigorous and human-centered discipline, capable of navigating uncertainty, an evolution supported by the SD.

1.5 Conclusion: How Should the Road Actually Appear?

Forensic science is increasingly recognizing the limitations of simplistic models that equate quality with rigid adherence to industrial quality management protocols, signaling a shift toward more nuanced and purpose-driven approaches. Such models could take away the discipline's epistemological depth and turn it into a bureaucratic exercise in following the rules. In this context, the Sydney Declaration (SD) stands out as a key turning point. Its significance does not reside in offering technical recommendations, but in delineating an epistemological and semiotic framework that reinstates forensic science to its scientific core. Crispino (2024) posits that the SD embodies the semiotic assertion of forensic science, acknowledging that the forensic trace is not a mere residue but a sign whose significance must be deciphered through a logical and transparent process aimed at a variety of purposes associated with secure societies.

This acknowledgment represents what could be referred to as Dimension A, the fundamental foundation of the discipline. Dimension A encompasses both ontology, the trace as sign, and axiology, the duty to produce valid, comprehensible, and transparent knowledge. It lays down rules that go beyond technical protocols, such as recognizing the inherent uncertainty of the trace (e.g. being generated by a unique context and compromised or incomplete) and inference (e.g. abduction where an observation may be due to more than on possible cause), clearly explaining reasoning, and making sure that results are shared in a way that non-experts can understand. Dimension A protects the epistemic integrity of forensic practice and stops it from becoming just a procedural or administrative task.

Dimension B, the control logics, is built on this foundation. It includes the methodological and normative frameworks that are meant to put the principles of the SD into action. ISO 21043 is the first international standard that is only for forensic science. ISO 21043 talks about the whole forensic process, from finding items (Part 2), to analyzing them (Part 3), interpreting them (Part 4), and writing reports (Part 5). It also sets up a common vocabulary (Part 1). Part 4: Interpretation is especially important within this framework. Morrison et al. (2025) and Berger (2025) say that it sets up a structured way for experts to think about things, separating investigative interpretation, which tries to come up with hypotheses or explanations, from evaluative interpretation, which looks at competing ideas within the likelihood-ratio framework. The standard says that all data and assumptions must be clearly documented, methods must be validated, and limitations must be clearly stated. This promotes both accountability and consistency across jurisdictions.

Dimension B also includes more general standards that are widely used in forensic practice. For example, ISO/IEC 17025 sets general requirements for the competence of testing and calibration laboratories, and ISO/IEC 17020 sets rules for conformity assessment for inspection bodies, including those that investigate crime scenes. These standards are not only for forensic use, but they are still very important for QA, accreditation, and getting forensic laboratories recognized around the world. In addition to ISO 21043, they make up a set of rules that help forensic science be more comparable, reproducible, and credible.

The relationship between Dimension A and Dimension B is neither linear nor uniform. Instead, it can be viewed as a quantum multiverse where both exist, although not always in the same way. Dimension A is foundational and has its own theoretical nature that can be operationalized on its own, while Dimension B depends on both explicit and implicit conditions. Although the two work well together and would help forensic professionals understand and act much better professionally, this is not often the case, at least in challenging environments. In environments with ample resources, characterized by accredited laboratories, skilled personnel, and reliable infrastructures, Dimension B can be comprehensively executed, integrating ISO 21043 with ISO/IEC 17025 and ISO/IEC 17020 to create stringent QA systems. In such cases, the interplay between foundational epistemic principles (Dimension A) and operational normative frameworks (Dimension B) yields a forensic practice that is both scientifically robust and socially legitimate.

However, in difficult situations where resources are scarce, institutions are weak, or the judicial system is overloaded, Dimension B cannot always be fully put into action. International accreditation schemes often involve significant costs and time commitments, particularly for activities such as periodic audits, technical validations, and proficiency testing. Local resources may not be able to handle all of this. Imposing these frameworks universally may lead to unintended consequences, such as the exclusion of laboratories unable to comply, or the promotion of superficial adherence that creates an illusion of compliance without genuinely enhancing scientific quality.

In these situations, Dimension A's implementation becomes critical. Even without complete quality control systems, the epistemological and semiotic principles of the SD can direct forensic practice in scientifically valid manners. Recognizing the trace as a sign, utilizing clear logical reasoning, and articulating uncertainty offer basic assurances of quality that can be implemented without expensive accreditation programs. In this sense, the ultimate objective is not to do away with regulations, but to return forensic practice to its original scientific meaning, ensuring that forensic science is more than a ritual of compliance and remains an autonomous epistemic endeavor.

This observation has direct implications for numerous regions in Latin America, Africa, and Asia, where forensic systems function amid structural instability. In these kinds of situations, Dimension A is the most important place to start. It enables forensic scientists to formulate clear and logical conclusions, even when operating with limited resources. As economic and institutional conditions improve, elements of Dimension B, such as ISO 21043, ISO/IEC 17025, ISO/IEC 17020, and related frameworks, can be progressively implemented, reinforcing the foundational principles already established.

In conclusion, the SD (Dimension A) and international standards like ISO 21043, ISO/IEC 17025, and ISO/IEC 17020 (Dimension B) are not mutually exclusive options; they are two parts of the same considerations that must work together. The first delineates the epistemological and semiotic underpinnings of forensic science, whereas the second sets the methodological framework for its implementation. In contexts abundant in resources, both dimensions can be fully actualized, resulting in a sophisticated and cohesive forensic practice. In contexts with limited resources, Dimension A must be the most important part, making sure that forensic science stays scientifically and socially valid while also making it possible for Dimension B to be added gradually.

When viewed through this dual lens, forensic science can be seen as a transformative field that maintains its independence, rigor, and social relevance while broadening its scope in response to new challenges. Developing a strong forensic culture, based on thorough education, institutional dedication, and constant innovation, will not only ensure its reliability but also enable the forensic field to appropriately meet standards, improve justice systems, and proactively address the evolving requirements of global society in diverse environments, starting with the most challenging.

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